

TITLE OF THE INVENTION**PROCESS AND APPARATUS FOR TREATING BIOSOLIDS FROM
WASTEWATER TREATMENT**

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CROSS-REFERENCE TO RELATED APPLICATIONS

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This application is a continuation-in-part of Application Serial No. 09/019,530, filed on February 5, 1998, and a continuation-in-part of Application Serial No. 09/233,532, filed on January 20, 1999.

FIELD OF THE INVENTION

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The invention relates generally to a new process for the treatment of biosolids resulting from the treatment of biological wastewater streams. More particularly, the invention comprises an autothermal aerobic process for treating biosolids where the oxygen/reduction potential is controlled by adjusting the amount of shear generated through jet aeration devices and/or adjusting the amount of oxygen-contouring gas provided to the process. The invention provides for a truly aerobic environment under which thermophilic microorganisms will thrive.

BACKGROUND OF THE INVENTION

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Wastewater such as sewage streams generally have various naturally occurring and/or man-made contaminants, notably organic contaminants. In a remarkable display of the versatility of nature, some naturally occurring microorganisms have the ability to consume these contaminants for their own life processes, thereby turning what is an undesirable pollutant into (for their purposes) a beneficial nutrient or food source. The wastewater treatment industry frequently capitalizes on the ability of these microorganisms by using such

microorganisms in facilities that treat wastewater streams to destroy the contaminants and break them down into basic compounds. Wastewater streams are fed into tanks or ponds that maintain conditions conducive to microorganism activity. Typically, the microorganisms which consume the targeted contaminants are mesophilic and thrive at temperatures in the range of about 25 to about 50 degrees Celsius.

The desired result of this type of wastewater treatment is the destruction of organic contaminants, but a by-product of this type of treatment is the production or increase of a biomass or biosolids comprised of the microorganisms. The biosolids yield from waste water treatment can range from about 0.1 pound of biosolids per pound of biological oxygen demand (BOD) removed to about 1 pound of bacteria per pound of BOD removed. A more typical range of biosolids yield is from about 0.3 pounds to about 0.6 pounds of bacteria per pound of BOD removed. Disposal of this biosolids may still be problematic, even after many contaminants have been consumed by microorganisms. One problem arises from the pathogenic nature of many microorganisms, such as the Fecal Coliform group of organisms; although such microorganisms have proven beneficial in consuming contaminants, they themselves may pose a danger to human health and are disease causing organisms. These include but are not limited to certain bacteria, protozoa, viruses and viable helminth ova. Regulations by states and/or the federal government impose restrictions upon land disposal of materials containing pathogenic microorganisms. It is desirable to treat biosolids so that one can easily and legally dispose of the biosolids on land or under ground.

Suitably treated biosolids may even prove to have beneficial uses. Under certain circumstances, it may be used as a soil conditioner or fertilizer.

Another problem with the biosolids may arise from the sheer volume of biomass generated. Costs associated with the production and disposal of biosolids include both capital costs and operating expenses, such as biosolids disposal costs, trucking costs, material handling costs, management costs, and liability costs associated with disposal. Most if not all of these costs depend on the volume of biosolids at issue, and a reduction in the amount of biosolids can make an economically unfeasible operation into a profitable one. Methods which will reduce the mass and/or volume of biosolids to be disposed have significant commercial and environmental benefits.

Biosolids also contains other materials including microorganisms which are not pathogenic in nature. Typically the biosolids includes a group of microorganisms that thrive in what is generally referred to as the thermophilic temperature range. These thermophilic microorganisms are normally not harmful to humans, and there are both aerobic and anaerobic bacteria that thrive within the thermophilic range. This invention is especially interested in the aerobic microorganisms. Although the temperature ranges for classification of bacteria varies somewhat depending upon who is describing the range, thermophilic activity usually takes place within the range of from about 45°C to about 70°C. In contrast, pathogenic bacteria usually thrive within what is referred to as a mesophilic range

which is from about 25°C to about 37°C or the normal body temperature of humans, and may begin to die at about 38°C.

Therefore, various methods have been proposed and practiced for treating the biosolids that results from treatment of wastewaters. Biosolids may be treated aerobically or anaerobically, with different microorganisms, conditions and results. Among the methods of biosolids treatment is autothermal thermophilic aerobic digestion ("ATAD"). ATAD capitalizes on the presence of materials in the biosolids such as naturally occurring microorganisms which are not pathogenic or harmful to humans but which will kill pathogenic microorganisms. Typically, these are thermophilic microorganisms which thrive at temperatures of from about 45°C to about 70°C.

A preferred temperature for thermophilic microorganisms is approximately 65°C. When this preferred temperature is maintained during the treatment of a wastewater biosolids, the reaction time for destruction of mesophilic microorganisms at 65° centigrade for purposes of meeting governmental regulations is approximately three quarters of an hour, as established by the Environmental Protection Agency's Standards for Use and Disposal of Sewage Biosolids, 40 CFR, Part 503. Three hours is an easily obtained processing time for most biosolids treatment facilities, since biosolids is often pumped once every twenty four hours from the waste water treatment plant.

In a typical ATAD process, biosolids resulting from wastewater treatment is treated in a reactor, which operates at a temperature in the thermophilic range, i.e., from about 45°C to about 70°C. Temperatures above

the above this range do not allow the thermophilic microorganisms to thrive and may even result in their destruction. Within this temperature range, thermophilic microorganisms are active in an aerobic process where they consume oxygen, which must be provided in the solution.

An advantage of an aerobic process using thermophilic microorganisms is that their use of oxygen is an exothermic reaction. The heat released as a result of this reaction raises the temperature of the biosolids solution. As the temperature rises above the mesophilic range, mesophilic microorganisms are killed and consumed by thermophilic microorganisms. It has been estimated by others that 9000 BTUs may be released for every pound of volatile suspended solids destroyed. The interrelated cycle processes in which exothermic reactions trigger additional exothermic activity by thermophilic microorganisms results in an autothermal process and thereby creates an autothermal environment by virtue of the maintenance of relatively high temperatures.

Pathogens could also be destroyed through the direct application of heat from an outside heat source to the biosolids solution. By directly heating the biosolids to temperatures that are inhospitable for mesophilic microorganisms, these pathogens may be killed. However, this type of treatment (without the action of thermophilic microorganisms) is costly and wastes energy, since the amount of heat that must be directly applied to raise the temperature of the biosolids mass is substantial.

A major challenge in operating an aerobic biosolids treatment process is to keep the process sufficiently

aerobic by meeting or exceeding the oxygen demand while operating at the elevated temperatures in which thermophilic bacteria thrive. One reason why this is difficult is that as the process temperature increases, the saturation value of the residual dissolved oxygen decreases. That is, a higher temperature results in less oxygen remaining in the biosolids solution. Another reason is that the activity of thermophilic microorganisms increases with higher temperature. This higher activity results in increased oxygen consumption by the microorganisms. Hence, greater amounts of oxygen must be imparted to the biosolids solution.

Another major challenge is to operate the process in an autothermal condition while still maintaining some control over the operating temperature. In an autothermal process, the process operates at a temperature higher than ambient without adding heat or by adding less heat than would ordinarily be needed to maintain the process at that temperature. In the biosolids treatment industry, autothermal processes capitalize on the exothermic nature of the action of the thermophilic bacteria in breaking down and consuming mesophilic bacteria or other organic compounds. The use of autothermal processes can obviate the need for external heat supply. However, it is still desirable or necessary to have some means of controlling the temperature of the process.

The need to control temperature has been previously identified and discussed in U.S. Patent No. 5,587,081, which discloses a method of controlling temperature by varying the proportion of fresh air versus recycled air injected into the biosolids. By increasing the amount of

fresh cool air introduced, the reactor is cooled. However the inventor believes it is important to use fresh air in the injection process because recycled air is not as effective in providing oxygen for thermophilic bacteria to thrive. The process described in U.S. Patent No. 5,587,081 does not appear to take into account the fact that recycled air, although warmer than fresh air, has less oxygen and will generate less exothermic reaction and heat from the thermophilic microorganisms. The recycled air has a lower content of oxygen than is found in ambient air. This results in less oxygen being imparted to the biosolids solution by the recycled air. Although at first glance, it may appear that the effect of the reduced oxygen content is minimal because the reduction in oxygen may be only a few percent, in practice the reduced oxygen content results in insufficient oxygen being imparted to the solution to create a truly aerobic environment for the aerobic microorganisms to thrive.

Various apparatus and methods have been used to inject an oxygen containing gas stream into a biosolids solution. For example, spargers, diffusers and aerators of various designs and configurations have been used. It is the inventor's opinion that the best apparatus to deliver the necessary oxygen is the aeration jet. One such aeration jet has been developed by Mass Transfer Systems, Inc., ("MTS") 100 Waldron Road, Fall River, Massachusetts. MTS has been purchased by Waterlink and have been put under its biological wastewater systems division, which lists its address as 630 Currant Road, Fall River, Massachusetts, USA 02720. A product brochure by MTS is enclosed herein and incorporated by reference.

By using the aeration jet, it is possible to create finer air bubbles along with higher shear which results in greater introduction of oxygen into the biosolids solution. There are many other advantages associated with the aeration jet, including better mixing. As the biosolids treatment occurs and mesophilic bacteria are broken down, carbon dioxide, water and ammonia (as well as other organic compounds) are produced when the protoplasm within the cell is released into the biosolids solution. The ammonia raises the pH of the solution and causes a noxious odor. Additionally, cell breakdown results in foam. It is desirable to have some means to treat odor and foam.

A typical method of controlling foam has comprised breaking the walls of the foam bubbles by manual or physical means. For example, some reactors have employed one or more cutting blades rotated by a motor. The blades spin through the foam layer, thereby rupturing foam bubbles, converting the foam back into a liquid. There are disadvantages to this approach for controlling foam, including maintenance and energy costs and efforts, particularly for a high rpm motor. Furthermore, the cutting blades may erode over time and require periodic replacement. Another disadvantage is that the motor that rotates the cutting blades is typically placed at the top of the reactor (outside the biosolids solution and the foam). However, the heat that can build up at the top of the reactor may shorten the life expectancy of the motor.

SUMMARY OF THE INVENTION

The inventive process has been referred to by its inventor as the THERMAERO[®] Process. The invention provides a method for controlling the temperature of an autothermal process by adjusting the flow rate(s) through a jet aeration nozzle of circulated biosolids solution and/or oxygen-containing gas, thereby adjusting the rate of exothermic reaction from the interaction of oxygen with aerobic thermophilic microorganisms. The mechanism by which the biosolids flow rate and/or gas flow rate affects the reaction rate is through the amount of shear produced as the biosolids solution mixes with the oxygen-containing gas stream in the jet aeration nozzle. A higher amount of shear induces more reactions by the thermophilic organisms, thereby producing more heat. Lowering the biosolids flow rate and/or the gas flow rate results in less shear, which in turn induces less exothermic reaction by the microorganisms.

By maintaining an autothermal, truly aerobic treatment environment, numerous process advantages ensue as well as a better digested biosolids product. Objects of the present invention include significantly reducing the volatile solids in the biomass, reducing the total mass of biosolids and producing a stabilized material suitable for land disposal. Another objection of the present invention is to create and maintain a truly aerobic environment for the treatment of waste water biosolids. A truly aerobic biological process has sufficient oxygen present to support the living organisms' respiration rates and does not allow an anoxic condition to occur.

The THERMAERO[®] Process which incorporates the present invention involves the surprisingly effective use of lower air flows and higher liquid flows. Counterintuitively, the use of a lower airflow can actually increase the amount of oxygen imparted into solution. It is believed that using a lower air flow process results in the injection of extremely fine bubbles into the treatment solution and higher surface renewal of the solution.

The present invention facilitates the treatment of biosolids in an autothermal process by removing a high percentage of water and increasing the organic concentration in a biosolids thickening process that precedes introduction of the biosolids into the treatment reactor. By thickening the biosolids, the volume of the biosolids solution may be significantly reduced, thereby enabling greater temperature control through the use of liquid flow rate.

The inventive process may be tailored to virtually any individual application. Different industrial plants have different product mixes with different sets of constituents. The complexity of the organic chemistry can vary from short chain molecules that are readily broken down to long chain molecules that are difficult to break down. The THERMAERO[®] Process has the flexibility to deal with varying plant conditions and can operate at varying liquid depths, at varying hydraulic and solids retention times and operate as a single tank reactor or multiple tank reactors.

In the preferred embodiments of the present invention, the temperature of a truly autothermal aerobic process is controlled through a variable frequency drive

on a jet motive pump which circulates biosolids through the jet aeration device into the reactor. Reactor temperature is controlled by varying the force in which the biosolids solution is circulated or re-circulated into the reactor through an aeration jet or other suitable means. In other embodiments, reactor temperature is controlled through the air pump used to control the flow rate of oxygen-containing gas through the jet aeration device.

In the present invention, the perceived problem of foaming caused by the treatment process is turned into an advantage. The inventor has noted that foam can act as an insulator between the biosolids solution and the air in the top of the reactor. In a typical reactor, the reactor is vented to the atmosphere so that it is not under pressure. As a result, the temperature of the air in the reactor is affected by the temperature of outside the reactor; in some cases, the temperature of the air in the reactor may be the same as the ambient temperature outside. By refraining from destroying all the foam bubbles, it is possible to use the foam as an insulator between the biosolids solution and the air in the reactor. Preferably, a foam control system is operated to maintain a layer of foam having a depth of from about four to about eight feet, preferably about six feet.

The inventive process may be used to treat a biosolids solution comprised of the products of waste water treatment and thermophilic bacteria capable of digesting mesophilic bacteria. The process comprises the steps of (a) thickening biosolids solution before it first enters a biosolids treatment reactor to a concentration of from about 3% to about 6% solids; (b)

mixing a portion of biosolids solution with an oxygen-containing gas stream using a jet aeration device; (c) injecting a mixture of the oxygen-containing gas and biosolids solution into a reactor at a flow rate which introduces sufficient oxygen into the study solution so that the treatment environment is substantially constantly aerobic; and (d) controlling the temperature of the biosolids solution by adjusting an amount of shear generated through the jet aeration device. In some embodiments, the amount of shear (and the temperature of the biosolids solution) is controlled by adjusting the liquid flow rate of biosolids through the jet aeration device while keeping the flow rate of oxygen-containing gas constant. In most embodiments the portion of biosolids solution mixed with oxygen-containing gas in the jet aeration device will be recirculated biosolids that has been removed from the general biosolids solution in the reactor and pumped through the jet aeration device.

The inventive process may also include the step of wasting a portion of treated biosolids wherein the wasting step is performed in the same apparatus in which the thickening step is performed. "Wasting" is a term used in the industry to mean dewatering biosolids prior to its disposal.

Alternate embodiments of the present invention comprise an apparatus for autothermal aerobic treatment of wastewater treatment biosolids. That apparatus comprises a means for concentrating a wastewater treatment biosolids to a concentration of at least about 3 percent solids. Among the suitable means for concentrating the biosolids solution are a horizontal

solid bowl-decanting centrifuge, a gravity belt, a rotary drum thickener, dissolved air flotation, gravity settling, or the application of evaporative heat. The apparatus also comprises a reactor having an inlet from said concentrating means for the introduction of at least one biosolids and a jet aeration device affixed to the bottom of the reactor.

The jet aeration device comprises an air header having one or more openings through which a gas transported through the air header may exit the air header; a liquid header running parallel to and/or concentric with the air header and having one or more openings through which a biosolids solution transported through the liquid header may exit the liquid header; an outer nozzle extending from the liquid header and having an opening on its side; an inner nozzle from the liquid header and contained within the outer nozzle; one or more air passage connections from the air header to the outer nozzle which connects the air header to the liquid header and provides a closed path for air from the air header to travel to the outer nozzle and enter the outer nozzle through its side opening; and liquid from the liquid header are mixed in the outer nozzle. The apparatus comprises an air distribution pipe connected to the air header, which provides an oxygen-containing gas from outside the reactor; and a liquid outlet located at or near the bottom of the reactor, which allows biosolids solution to exit the reactor. The apparatus may optionally include a motive pump connected to the liquid outlet such that biosolids solution is withdrawn from the reactor by the motive pump. Attached to the motive pump is a motive pump conduit that leads from the motive pump

to the liquid header such that biosolids solution is pumped through the conduit into the liquid header and forced through the inner nozzle by force of the motive pump.

5 The present invention may also include apparatus for automatically sensing and controlling the temperature in the reactor by adjusting the rate at which liquid is circulated into the reactor through the jet aeration device. Alternatively or additionally, the present
10 invention may include apparatus for automatically sensing and controlling the oxidation/reduction potential ("ORP") of the solution in the reactor, by adjusting the rate at which biosolids, liquid or gas is circulated into the reactor. This apparatus will typically include a
15 temperature sensor and/or an ORP sensor within the reactor and means for automatically controlling the motive pump and/or air blower. In other embodiments, a physical property other than temperature or ORP may be sensed or monitored. Suitable means for automatically
20 controlling include a programmable logic controller ("PLC"), a computer, analog signal or a microprocessor. This automatic control means is operatively attached to the temperature sensor and/or ORP sensor and the motive pump and/or air blower such that based on the temperature
25 of the biosolids solution in the reactor as measured by the temperature sensor, and/or the ORP of the solution as measured by the ORP sensor, the automatic control means will instruct the motive pump and/or the air blower to adjust the flow of biosolids solution and/or the air flow
30 in order to adjust the amount of solution and/or oxygen-containing gas into the reactor. This can effect the

temperature and/or ORP of the biosolids solution in the reactor.

Apparatus embodying the present invention may also comprise a secondary cooling system, which comprises a cooling jet nozzle located in the reactor above the level of the jet aeration device; and a cooling conduit extending from the motive pump conduit to the cooling jet nozzle such that biosolids solution traveling through the cooling conduit loses heat to the surrounding environment.

In one embodiment of the present invention, the reactor holds a biosolids solution having a depth of at least about 24 feet. Another benefit of the present invention is it can be used in larger reactors. Because the invention can be used in larger reactors, the residence time of biosolids in a reactor can be increased so that biosolids may remain in a single reactor throughout the entire treatment period.

As discussed above, the foam created during the treatment process can be used to advantage, as an insulator between the biosolids solution and the air in the reactor. Nonetheless, a reliable foam control system is necessary to maintain a layer of foam at a desirable depth and prevent an excess of foam from escaping from the reactor.

In a further refinement of the THERMAERO[®] Process, an inventive method and apparatus for foam control system has been developed. This method and apparatus may be used in conjunction with or separately from the other steps and apparatus of the THERMAERO[®] Process described herein.

In one embodiment, the method comprises the additional or separate steps of generating a layer of

foam on top of the biosolids solution, transferring a portion of the layer of foam from on top of the biosolids solution into the biosolids solution through a foam transfer pipe, and converting at least some of the portion of the layer of foam into liquid during transfer through the foam transfer pipe. The foam transfer pipe preferably includes a static mixer or other means that impart a dynamic mixing action to the foam, thereby rupturing or collapsing foam bubbles. Dynamic mixing action is action that imparts turbulence or energy that causes foam bubbles to collapse or rupture. One way to impart dynamic mixing action is to cause the fluid to have turbulent flow; another way is to mix the fluid or cause the fluid to move in a swirling motion. Alternately, the method may comprise the steps of transferring a portion of the foam from on top of the solution into the solution through the foam transfer pipe; mixing the foam in the foam transfer pipe so that at least some of the portion of foam is converted to liquid while passing through said foam transfer pipe; and drawing at least a portion of foam (which may be converted to liquid) by suction through at least a portion of the foam transfer pipe. The source of the suction may be an outer nozzle of a jet aeration system similar to those described herein, except that one outer nozzle is not connected to an air header; instead, it is dedicated to the foam transfer pipe. As fluid flows through the inner nozzle, it generates a vacuum or draw in the outer nozzle that pulls or sucks liquified foam from a foam transfer pipe that is fluidly connected to the side of the outer nozzle.

The foam control apparatus is preferably used in connection with the ATAD treatment reactor comprising a jet aeration system as described above. The foam control apparatus comprises a foam transfer pipe having a top opening, a bottom opening and an internal surface, wherein said top opening is at least above an anticipated level of a solution (for example, a biosolids solution), the bottom opening is at least below the anticipated level of the solution and is fluidly connected to a suction source. The suction source is preferably an outer nozzle of a jet aeration device that is dedicated to the foam transfer pipe or another venturi device. The foam transfer pipe preferably has a static mixer disposed therein. The static mixer may be affixed to the internal surface of the foam transfer pipe.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a cross section of a jet aeration nozzle used in the invention.

Fig. 2 shows a biosolids treatment system as a integrated part of a waste water and biosolids treatment facility.

Fig. 3 shows a biosolids treatment reactor and associated process equipment for the biosolids treatment process.

Fig. 4 shows a temperature correlation chart for a hypothetical installation of the invention, wherein the appropriate pump speed is set for a given temperature of the biosolids solution.

Fig. 5 shows foam control equipment for a treatment reactor, including a jet aeration system and a foam transfer pipe.

Fig. 6 shows an approximation of the estimated oxygen demand in an aerobic treatment of biosolids.

DETAILED DESCRIPTION OF DRAWINGS AND PREFERRED EMBODIMENT

5 The inventor contemplates that preferred embodiments of the invention will involve the use of a jet aeration device. Fig. 1 shows a cross-section of a jet aeration device 1. The device includes a liquid header 3 and an air header 5. The liquid header and the air header may
10 be longitudinal, circular or radial in shape. The liquid header 3 transports a liquid such as an untreated or recycled biosolids stream. The liquid header 3 has a relatively small opening or inner nozzle 7 which allows the liquid to exit from the liquid header into an outer
15 nozzle 9 or other conically shaped structure. The air header 5 also has an air header opening 11 which allows the gas to exit through an air passage way 13 into the same outer nozzle 9. In the outer nozzle 9, the gas and the liquid mix so as to create a shear that induces the
20 exothermic action of the thermophilic microorganisms. The air header 5 carries a gas such as an oxygen-containing gas useful for an aerobic process. Typically the source for the oxygen-containing gas is ambient air outside the reactor; however, the gas may be obtained
25 from any source provided that it contains sufficient oxygen for a truly aerobic process. The inventor believes that such a gas should have at least the concentration of oxygen found in ambient air (approximately 21.9 percent by volume).

30 The jet aeration device 1 must have the ability to transfer a high amount of oxygen-containing gas into a high suspended solid concentration while completely

mixing the reactor contents. When the liquid is mixing with the air, a shear is produced. The inventor contemplates that the flow rate of biosolids solution through the inner nozzle of a jet aeration device would be in the range of from about 30 feet/second to about 50 feet/second.

Fig. 2 is a schematic of an integrated treatment system for the initial treatment of wastewater and the secondary treatment of the biosolids resulting from that initial treatment. Wastewater is treated in an aeration basin 17, resulting in the production of an effluent comprising biosolids and water. The biosolids typically has various mesophilic and thermophilic microorganisms. The effluent is transported to a clarifier 19 which separates a portion of biosolids solution to be disposed of. The clarifier 19 can accept biosolids from a number of sources and of several different make-ups. After the biosolids solution leaves the clarifier 19, a portion of the biosolids may be returned to the aeration basin 17 to insure that it has sufficient amounts of active microorganisms to devour the waste water contaminants. Another portion of the biosolids will be sent for treatment according to the present invention prior to ultimate disposal. To the biosolids that is to be treated, one may choose to add one or more charge neutralizing polymers from polymer containers 25 to allow for greater flocculation of the biosolids. Alternately, a thickening polymer may be added to the biosolids solution as it is being concentrated.

The portion of biosolids to be treated and disposed is transferred to a means for concentrating the biosolids to a higher solids concentration. Any suitable means may

be used for concentrating the biosolids solution. One preferred means is a horizontal solid bowl-decanting centrifuge **21**. Other means include a gravity belt, a rotary drum thickener, a DAF, gravity settling, or the application of evaporative heat. The centrifuge may be controlled by a separate PLC that can be programmed to operate on more than one process curve. A PLC can monitor the torque that is produced on the biosolids cake and adjust the scroll speed accordingly to achieve consistent results. Typically, the solids content of a biosolids prior to treatment is from about 0.5% to about 1.5% with a volatile solids content of from about 65% to about 90%, with 80% preferred. The inventor has found it desirable to concentrate the biosolids solution to a solids content of from about 3% to about 6%, with 5% to 5.5% being preferred, prior to treating the biosolids solution. The inventor has found it necessary to thicken the biosolids to a solids content of from about 3% to about 6% in order to run an optimal autothermal treatment process.

From the centrifuge, the biosolids solution is transferred to a treatment reactor **23** via a feed line **24**. After treatment, digested biosolids may be removed from the reactor **23** via a removal pipe **27** which transfers the biosolids to the same or a different concentrating means. Preferably the same concentrating means **21** is now used to reduce the water content of the treated. A coagulant tank **29** for a coagulant such as ferric chloride may also be provided and operatively connected to the removal pipe **27** so that coagulant may be introduced into digested biosolids. From the concentrating means, the biosolids is removed by a conveyor system and sent for disposal.

Biosolids will generally be removed from the reactor on a batch per day basis. The volume of biomass removed from the reactor will typically be about the same as the volume of biosolids to be introduced into the reactor for treatment that day. Using the same concentrating means to remove water before and after treatment in the reactor may achieve substantial savings on the cost of capital equipment.

Fig. 3 shows a treatment reactor 33 in greater detail and associated process equipment for the biosolids treatment process. The reactor 33 contains a biosolids solution that is treated according to the inventive process. The reactor contains an arrangement or unitary sequence of jet aeration devices 35 (as described above and shown in cross-section in Fig. 1) affixed to the bottom floor of the reactor. Preferably, the outer nozzles of the jet aeration device 1 point around the reactor.

A motive pump 37 may be employed to circulate the biosolids solution through the liquid header 35a (shown in cross-section in Fig. 1 as liquid header 3). The motive pump 37 pumps the biosolids solution through the liquid header 35a of the jet aeration device 35. It is preferred that the motive pump 37 have a variable frequency drive 39 or other means of varying the liquid flow, which may vary the force generated by the motive pump 37, thereby varying the flow rate and pressure of the biosolids solution through the liquid header 35a and through the outer nozzle 9 (shown in Fig. 1). A varying flow rate is desirable because it is desirable to have the ability to control the liquid flow rate through the

liquid header **35a** in order to control the amount of energy generated by shear.

Air or another oxygen-containing gas is introduced from outside the reactor through an air distribution pipe **41** whose upstream end is connected to one or more air blowers **43** which blow air or another suitable oxygen-containing gas through the air distribution pipe **41**. The air distribution pipe **41** transports air or gas to the air header **35b** (shown in Fig. 1 as air header **5**). The air header **35b** may be detached from or affixed to the liquid header **35a**.

Different amounts of energy are needed at different phases of the treatment operation. During the start-up phase, when a batch of untreated biosolids solution is first introduced into the reactor **17**, a large amount of shear is required to begin the exothermic reaction to the extent necessary to bring the reactor contents up to the operating temperature, which is from about 55 degrees Celsius to about 65 degrees Celsius, alternately about 63 degrees Celsius. The motive pump **37** is operated at the speed necessary to obtain a desired shear due to a high liquid flow rate until the viscosity of the biosolids solution has reached a normal operating level. At that time, the motive pump **37** is slowed so that the liquid flow rate is sufficient to sufficiently mix the contents of the reactor so that exothermic reactions continue and to inject oxygen-containing gas into the biosolids solution flowing from the liquid header. After start-up, the biosolids solution in the reactor **33** should operate at a self-regulating autothermal temperature at which the heat provided by exothermic reactions is in equilibrium with the heat lost to the outside environment.

A temperature sensor may be provided inside the reactor to measure the temperature of the biosolids solution and send a signal to a suitably programmed PLC connected to the motive pump. An indirect method of sensing the temperature of the biosolids solution is to measure the oxygen reduction potential ("ORP") of the biosolids solution. ORP is directly related to temperature. A high negative value for ORP indicates that the biosolids solution has a high oxygen up-take requirement and that the speed of the motive pump should increase to provide more oxygen and raise the temperature. Using an ORP sensor instead of a direct temperature sensor would require an additional set of data points connecting ORP values to temperatures for a given system.

A PLC may be programmed so that it will speed the motive pump and/or the air blower if the temperature of the biosolids solution drops below the minimum desirable temperature. Alternatively, a PLC may be programmed so that it will speed the motive pump and/or the air blower if the oxygen/reduction potential drops below the minimum desirable potential. Alternatively, a PLC may be programmed so that it will speed the motive pump and/or the air blower if some monitored physical property reaches a predetermined value. The effect of speeding the motive pump and/or the air blower will be to increase the liquid flow rate and/or the air flow-rate, respectively, in the jet aeration device and to increase the shear, thereby increasing the exothermic reaction by the thermophilic organisms. This increased reaction will provide additional heat, raising the temperature. Conversely, if the temperature of the biosolids solution

risers above the maximum desirable temperature, the PLC will send a signal to the motive pump, which slows the motive pump. This will reduce the liquid flow rate and shear, thereby reducing the level of exothermic reaction and heat produced thereby. In this way, the inventive system automatically maintains the temperature of the biosolids solution within a predetermined range through the liquid flow rate and/or the air flow-rate. The motive pump and the air blower is operated within a predetermined range of speeds that is set by the flow and pressure curve for each individual application.

Parameters for a PLC or other means of automatically controlling the motive pump must be uniquely generated for each particular installation because each installation has unique reactor and conduit configurations, biosolids concentrations, and pump characteristics. Typically, one identifies the corresponding temperature and pump parameters by plotting empirically determined temperature data points on the performance curve for the motive pump supplied by the seller of the pump. The highest desired temperature is plotted at the lowest desired RPM and corresponding flow rate for a given resisting pressure, or head. For example, for a model 3180/3185 pump, a minimum desired temperature of about 135 degrees F might be plotted at about 900 RPM, and the maximum desired temperature of about 155 degrees F might be plotted at about 500 RPM.

After the reactor contents have reached a desirable temperature, an appropriately programmed PLC device will cause the variable frequency drive to maintain the motive pump at a constant rate. During certain operating conditions, the exothermic reactions may create too much

heat. If the temperature of the biosolids solution is too high, the thermophilic microorganisms may not thrive or may be killed. Other possible adverse effects of having too high a temperature are excessive foam or odor.

5 To account for the possibility that the reactor's normal operating temperature is normal that the desired operating temperature, the present invention provides a secondary cooling system which is comprised of a fluid by-pass which allows re-circulated biosolids solution to

10 surrender heat.

An ORP sensor may be provided inside the reactor to measure the oxygen/reduction potential of the biosolids solution in millivolts or other units of electric potential difference. In effect, the ORP sensor

15 measures the oxygen level in the reactor. Oxygen level is an important parameter in an aerobic system, and it may be effected by different oxygen demands at different times within the solution. This is particularly true during or shortly after the feed cycle is begun, when the

20 oxygen demand in the reactor increases.

Fig. 6 is a graph showing an approximation of the estimated oxygen demand in an aerobic treatment of biosolids. Thus, a system that includes an ORP sensor is especially able to sense those times when oxygen demand

25 is higher than normal and adjust the oxygen supply so that the solution will remain truly aerobic. In at least some current system, the oxygen supply remains consistent through the treatment. One object of the present invention is to provide an oxygen delivery curve that is

30 close or identical to the oxygen demand curve, so that the amount of oxygen supplied is the same as or close to the amount of oxygen demanded in the treatment.

In a system that includes an ORP sensor, when oxygen demand increases, the millivolt reading on the ORP sensor decreases and may go into negative numbers. The ORP sensor periodically sends a signal to a PLC, which continually monitors the input signal. In one embodiment, the PLC will be programmed to determine an average trend line of the millivolt reading over a period of time, perhaps over the period of five minutes. The average trend line will be compared to a preset value that corresponds to a default setting of the motive pump(s) and/or the aeration blower(s). The present value can be determined and set on the PLC based on the pump curve of the jet motive pump(s) and the aeration blower(s).

Periodically the PLC will adjust the variable frequency drive for the motive pump(s) and/or the variable frequency drive for the air blower(s). A normal operating mode or minimum frequency for the variable frequency drive will be preset into the PLC. The normal operating mode can correspond to any reading on the ORP sensor, but will typically correspond to a value between 0 and 20 millivolts. The PLC will respond to the ORP sensor in an inverse fashion, that is, as the average trend line millivolt reading decreases, the frequency of the variable frequency drive will increase. The adjustment can occur independently with the pump(s) and blower(s) or simultaneously. This procedure will continue until the process stabilizes or the frequency is at 100% of the preset maximum pump and blower setting. The system will continue to operate at 100% capacity until the average trend line millivolt reading of the ORP sensor goes above the preset point typically between 0

and 20 millivolts. As the reading reaches or exceeds the preset point, the controller will decrease the frequency on the variable frequency drive of the blower. As stated earlier, the adjustment can occur independently with the pump(s) and blower(s) or simultaneously. This procedure will continue until both the pump and blower frequency setting are at the normal operating set points or minimum set points. The controller will continue to monitor the average trend line millivolt reading for the remainder of the daily feed cycle and make the appropriate adjustments while waiting for the next feed cycle to begin.

A major benefit of a control scheme comprising an ORP sensor inventive control scheme is energy efficiency. The control scheme supplies the required horsepower to increase oxygen supply when necessary and conserves energy when the demand is lower. Another extremely important advantage of this control scheme is that it may prevent sulfur compounds from reducing and producing unwanted and very foul odors in addition to keeping the production of unwanted volatile fatty acids to a minimum.

The secondary cooling system is generally a liquid by-pass that transfers the reactor contents above the foam layer and through a jet-cooling nozzle. This action exposes the reactor contents to the atmosphere above the foam layer, thus causing the reactor contents to release heat. The secondary cooling system may include a conduit 45 located outside the reactor which routes biosolids above the foam layer. This conduit 45 may be attached to the pipe leading from the motive pump back into the reactor. An actuated valve 46 may be placed so that the biosolids solution's access to the conduit 45 is controlled, perhaps through the PLC based on the reading

of the temperature sensor. The secondary cooling system may also comprise a cooling jet nozzle 47 at the downstream end of the cooling conduit. The cooling jet nozzle 47 injects the biosolids solution back into the reactor 33 at a predetermined location or height.

In one embodiment of the present invention, the air blowers 43 will typically operate at a constant volume. It is believed that greater process control is achieved by maintaining the air flow rate constant while varying the liquid flow rate to control temperature. In other embodiments, the air flow may be varied as a method of controlling temperature.

The present invention uses a lower air rate and a higher liquid flow rate to create an extremely fine bubble and a high shear factor. For example, whereas a typical air flow may be as high as 80 scfm, the present invention employs an air flow rate of approximately 10 to 25 scfm, alternately 16 to 20 scfm. Whereas a typical liquid velocity may be about 30 to 33 ft/s, the present invention generally employs a liquid velocity of about 40 to 55 ft/s. The result of the lower air rate and the higher liquid rate is an extremely fine bubble and a high shear factor.

Volatile suspended solids are live cells. The dead cells cause a putrescible odor. The present invention may be used with a reactor of any height or with a biosolids solution of any depth. However, it is preferred that the biosolids solution be at a depth of at least about 10 feet, alternatively at least about 24 feet, alternatively less than about 30 feet. It is believed that depths of about 24 feet are optimal because oxygen transfer increases with increased depth, as the

oxygen-containing gas is released into the biosolids solution at increased pressures. The maximum liquid depth of the biosolids solution (shown for general illustrative purposes in Fig. 3 as a line 53) for existing apparatus is set by the pressure limitation of the air blowers and the mixing limitation of the tank geometry. The minimum liquid depth (shown for general illustrative purposes in Fig. 3 as a line 55) is generally no lower than the center line of the positive pressure liquid pipe 51 leading from the motive pump 37 to the reactor 33.

In some preferred embodiments of the invention, foam is controlled by means other than physically contacting the foam to rupture its bubbles. Instead, foam is controlled in ways that do not physically contact the foam yet still rupture an appropriate amount of foam bubbles. One such way is the use of a sonic horn 49 to rupture foam bubbles through sonic waves of an appropriate frequency. The horn may be sounded at appropriate intervals so that sufficient foam remains to cover the biosolids solution but the danger of foam spilling over the top of the reactor is minimized. The sonic horn may be activated and controlled by a timer and a solenoid valve. In one embodiment of the inventive process, the sonic horn is activated for approximately five minutes with off-intervals ranging from between about ten minutes to about 55 minutes, preferably about 25 minutes.

The reactor 33 typically also has additional features which do assist in operation. The reactor 33 may have an overflow outlet 57 through which excess foam may escape and be diverted to a foam containment area or

container. The reactor 33 typically has vent 59 which allows the reactor volume to remain at atmospheric pressure and an off-gas outlet 61 at or near the top of the reactor 33 which is attached to a source of partial vacuum, thereby pulling off-gas out of the reactor 33. The off-gas is removed at a rate that exceeds the incoming volume of air and compensates for the air expansion that occurs from heating. The off-gas, which may have a foul odor, can be routed to the aeration basin 17 (shown in Fig. 2) where the contaminants which cause the foul odor can either be solubilized through pH and temperature reduction or adsorbed by the biosolids microorganisms and utilized for food. The reactor may also have a foam level detector 63 that will shut down the aeration blower 43 if the foam reaches too high a level.

After treatment in the reactor, the biosolids solution or a portion thereof is removed and transferred to the concentrating means so that it may be dewatered. After this concentrating step, the biosolids may be disposed.

Fig. 4 is a chart which correlates the temperature of the biosolids solution to the speed of the motive pump, the velocity of biosolids solution through the inner nozzle of the jet aeration system and the total dynamic head, which is a measure of pressure against which the jet aeration device injects biosolids solution into the reactor. The chart in Fig. 4 could be provided to a programmer to program a PLC to run the motive pump at the speed (in RPM) specified for each of the given temperatures. Based on this chart, the PLC would make the motive pump run at a speed of 770 RPM if the

temperature sensor measured a reactor temperature of 135 degrees F.

Although Fig. 4 is useful to show the relation between the plotted parameters, it may or may not be appropriate for a given installation due to the unique reactor characteristics and configurations and biosolids concentration associated with each installation. Fig. 4 is a hypothetical chart based on the inventor's approximation of an appropriate correlation.

A correlation chart for an actual installation can be made in the following way. First, after selecting the desired operating temperature, one finds the motive pump speed that corresponds to that temperature. This becomes the target pump speed. When the reactor temperature rises above the desired temperature, the PLC must be programmed to decrease the speed of the motive pump and vice versa. Generally, the maximum acceptable operating temperature will correlate to the lowest acceptable pump speed. Though the exact pump speeds associated with temperatures higher or lower than the desired temperature are somewhat subjective, it is preferable to have a series of possible pump speeds that correspond with the range of possible operating temperatures rather than having the pump run at its highest or lowest speeds in response to a variation from the desired temperature. This is preferable because it is easier on the system and more energy efficient.

Fig. 5 shows a foam transfer pipe 67 employed in a treatment reactor. In the embodiment shown in Fig. 5, the top opening 69 includes a foam collector 71 which opens to a layer of foam floating on top of a solution in the treatment reactor. The top of the foam 77 and the

top of the solution 79 are shown in a general, approximate fashion in Fig. 5. Foam is shown entering the top opening 69 through the foam collector 71. As the foam collects in the foam collector 71 and in the foam transfer pipe 67, a foam head pressure builds and forces the foam through the foam transfer pipe 67. This foam head pressure also exerts a force that may rupture foam bubbles. Foam head pressure may be measured in feet. The amount of foam head pressure exerted on the foam depends on the density of the foam itself. Generally, the layer of foam is generated by treatment of the solution or other reaction processes that take place in the reactor. Continuous foam production by a reaction process in a treatment reactor can produce the static energy sufficient to move the foam through the upper portion of the foam transfer pipe 69.

The foam collector 71 may be any shape, though a conical shape is preferred. The top of a conical foam collector 71 is referred to as a weir. A longer weir length or diameter will increase the ability of the foam collector to collect foam and direct it into the foam transfer pipe. As a result, the foam collector 71 may be a shorter distance above the top of the solution, or the foam layer may be smaller, while still creating sufficient static foam head.

The foam transfer pipe 67 may be circular, square or another shape. In Fig. 5, the foam transfer pipe 67 is circular and has a first diameter, and the bottom opening 73 has a second diameter. The foam transfer pipe 67 tapers so that the second diameter is smaller than the first diameter.

The foam transfer pipe **67** shown in Fig. 5 includes a static mixer **75**. A static mixer can impart dynamic mixing action to a fluid as that fluid passes by. The static mixer shown in Fig. 5 is expected to cause the foam to mix in a swirling motion. The static mixer may be immobile, thereby reducing or eliminating the moving parts and energy requirements and costs for controlling foam. A preferred form of static mixer comprises at least one helix-shaped protrusion (as shown in Fig. 5). The static mixer shown in Fig. 5 comprises a helix-shaped flat protrusion running along the interior surface of a foam transfer pipe, although the static mixer need not be attached to the foam transfer pipe. That is, the static mixer may be free-standing inside the foam transfer pipe. As a foam or other fluid passes by this helix-shaped protrusion, the foam or fluid may swirl or shear, which may thereby rupture bubbles that comprise foam. Other types of static mixers include off-hatching or spirals of any configuration running through the pipe. In a broad sense, a static mixer may be any impediment to fluid flow in the foam transfer pipe that creates a sufficient dynamic mixing action to rupture foam bubbles.

The foam transfer pipe **67** is fluidly connected to an outer nozzle **81** of a jet aeration device of the type shown in Figs. 1 and 3. However, this particular outer nozzle is dedicated to the foam transfer pipe and is not connected to an air header. A suction, vacuum or draw is created in the interior of the dedicated outer nozzle **81** by the liquid flow passing through the inner nozzle **7**. (A higher liquid flow generates higher suction or draw.) The liquid flow through the jet aeration devices creates a venturi action that pulls foam through the bottom

opening 73 into the dedicated outer nozzle 81. The foam head pressure enhances and works additively with the venturi action and allows the venturi to move a higher volume of foam. Thus, the foam transfer pipe uses these two forces to move foam. Through the dedicated outer nozzle 81, the foam (which is no longer entirely foam but now at least in part a liquid) is injected back into the solution to be treated. Although it is believed that most or all foam bubbles will be ruptured after passing through the static mixer, any remaining bubbles will likely be ruptured by the additional shear generated in the jet aeration system. Furthermore, the recirculation of foam back into the reactor can allow materials to be broken down into even simpler compounds which may eventually lose their ability to generate new foam bubbles.

Just as the liquid velocity passing through the inner nozzle 7 of the jet aeration system can control temperature by controlling the exothermic reaction rate, so can the liquid velocity control the foam level. By reducing the liquid velocity rate, less foam will be generated.

The amount of pressure required to rupture or collapse a foam bubble is defined by the surface tension of the bubble. Foam head pressure may be sufficient to rupture the foam bubble in some cases and return the foam to liquid form. In such cases, a static mixer may not be required. In other cases, it will be necessary to supply a dynamic force in addition to static head pressure to rupture foam bubbles. It is theorized that a static mixer 75 can supply this dynamic rupturing force by creating a pressure drop on the foam and by creating a

dynamic movement on the foam, thereby adding shear force to the already existing head pressure forces. The static mixer can also assure that the foam will not vortex while passing through the foam transfer pipe 69.

5 The foam transfer pipe 69 may be adjustable in height so that its operation is not limited to a particular level of solution or foam. One way to make the foam transfer pipe 69 adjustable is by making it a telescoping pipe.

10 The foam control method and apparatus described herein are not limited to use with jet aeration systems. They can be used with other venturi systems or other systems that generate a vacuum, suction or draw. However, jet aeration systems are preferred because of the
15 relatively high level of draw they can generate. Furthermore, the foam control method and apparatus are not limited to autothermal thermophilic aerobic digestion of biosolids; they may be used in connection with mesophilic aerobic digestion of biosolids; anaerobic
20 mesophilic or thermophilic digestion of biosolids; mesophilic or thermophilic biological treatment of soluble organic compounds, treated by aerobic or anaerobic technology; treatment processes in the chemical, petrochemical or pharmaceutical industries; and
25 any other process that requires mixing and generates foam.